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The impact of bilingualism on working memory in pediatric epilepsy

Amy L. Veenstra[1], **Jeffrey D. Riley**[2], **Lauren E. Barrett**[1], **Michael G. Muhonen**[3], **Mary Zupanc**[3], **Jonathan E. Romain**[1], **Jack J. Lin**[2], and **Grace Mucci**[1]

[1]Department of Pediatric Psychology, CHOC Children's Hospital

[2]Department of Neurology, University of California Irvine

[3]Neuroscience Institute, CHOC Children's Hospital

Abstract

Impairments in executive skills broadly span across multiple childhood epilepsy syndromes and can adversely affect quality of life. Bilingualism has been previously shown to correlate with enhanced executive functioning in healthy individuals. This study seeks to determine whether the bilingual advantage in executive functioning exists in the context of pediatric epilepsy. We retrospectively analyzed neuropsychological data in 52 children with epilepsy and compared executive function scores in monolingual versus bilingual children with epilepsy, while controlling for socioeconomic status and ethnicity. Bilingual children performed significantly better on the Working Memory scale than did monolingual children. There were no significant differences on the remaining executive function variables. The bilingual advantage appears to persist for working memory in children with epilepsy. These findings suggest that bilingualism is potentially a protective variable in the face of epilepsy-related working memory dysfunction.

Keywords

Bilingualism; Executive Functioning; Working Memory; Epilepsy

1 INTRODUCTION

Executive functions are a diverse but critical set of self-regulatory processes that include planning, initiating, and sustaining goal-directed behaviors, all critical to successful life performance [1–2]. Specifically, deficits in executive function are related to reduced quality of life[3], problems with psychosocial functioning, diminished educational achievement, and

Corresponding Author: Amy L. Veenstra, Ph.D., 1201 W. La Veta Ave., Orange CA 92868, Phone: 714-509-8481, Fax: 714-509-8756, aveenstra@choc.org.

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poor occupational outcomes [4]. Executive deficits do not appear to be syndrome specific, but instead are broadly affected in various epilepsy types [2, 5]. Consequently, it has become increasingly important to examine the influence of individual characteristics on executive function [6].

Bilingualism is one such factor known to differentially impact executive functioning. Specifically, typically developing bilingual children perform better than their monolingual peers on executive functioning tasks [7–8], including inhibition of attention to distractor stimuli, selectively attending to relevant information, mental switching between possible responses, and working memory [8–11]. It is theorized that certain areas of neurocognitive functioning within the executive domain is reinforced by processes related to bilingualism, resulting primarily from the practice of mentally switching between translations of two or more languages and selectively utilizing the language appropriate to the context, while simultaneously inhibiting other known languages [12]. Children who know more than one language, therefore, become more adept at using these executive skills, resulting in stronger mental control.

Although executive dysfunction is a common deficit found in children with epilepsy, investigation of the bilingual advantage in executive functioning has not been extended to this population. Research to date suggests that bilingualism could serve as a protective factor against some neurodegenerative processes [13–15], and likely works through the recruitment of different brain regions during these cognitive tasks [16–17]. Therefore, this study seeks to determine if the bilingual advantage in executive functioning persists in the context of a central nervous system (CNS) disease process that has broad negative effects on executive functioning. Specifically, we test the hypothesis that bilingual children with epilepsy will perform significantly better on executive functioning tasks when compared to monolingual individuals with epilepsy.

2 METHODS

2.1 Participants

A retrospective study identified 26 bilingual children between ages 6 and 18 with epilepsy who had completed a comprehensive neuropsychological evaluation between 2006 and 2015 at the Children's Hospital of Orange County. Board certified pediatric epileptologists, with supportive information from routine and/or long-term video EEG monitoring, confirmed all epilepsy diagnoses. Information regarding seizure foci/diagnosis was obtained from clinical notes and EEG reports located in the electronic medical record.

Inclusion criteria for this study included a formal diagnosis of epilepsy, English language proficiency and a General Ability Index (GAI) >70. The control group consisted of 26-age-matched monolingual children who met inclusion criteria. Exclusion criteria for both groups included diagnosis of Autism Spectrum Disorder. Participants selected for the control group were the closest age matches evaluated between 2006 and 2015. At the time of their evaluation, participants' ages ranged from 6.40 to 17.75 years of age (M = 12.62 years; SD = 3.31). Fifty-eight percent (n = 30) of the participants were female. Consistent with local demographics, the majority of the children were of Latino (42.3%) or European (30.8%)

decent, with a smaller number of children of Asian (19.2%) or multiracial (7.7%) origins. Children were primarily right hand dominant, with 8% (N = 2) of monolingual and 12% (N = 3) of bilingual children left hand dominant.

2.2 Procedures

Study procedures were performed with the approval of the Institutional Review Board of Children's Hospital of Orange County. The neuropsychological evaluation was performed as part of clinical care and, thus, the specific test battery varied. Domains assessed and included in this study are intellectual functioning, working memory, impulsivity, mental flexibility, and verbal fluency (Table 1). The general ability index (GAI) was used as a measure of intelligence, rather than full scale IQ, because full scale IQ includes working memory, a variable of interest in our study. All tasks were administered in English. Standard clinical care procedures included background questionnaires completed by parents. Data on parental education level and job type were obtained from this form to determine social economic status (SES) level using The Barratt Simplified Measure of Social Status [18].

2.2.1 Assessment Methods Utilized—Neuropsychological tests consisted of standardized measures that have consistently demonstrated good reliability and validity [19]. Intellectual functioning was assessed using Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV, [20]), Wechsler Abbreviated Intelligence Scale (WASI, [21]), or Wechsler Adult Intelligence Scale, 4th Edition (WAIS-IV, [22]). Working memory was measured using the Working Memory Index from the WISC-IV or WAIS-IV. Within the executive functioning domain, several areas were assessed using multiple measures. Mental flexibility on nonverbal sequencing tasks was measured using either Trails B from the Trail Making Test or Condition 4 (Letter-Number Switching) from the Delis-Kaplan Executive Functioning System (D-KEFS) Trail Making Test [23]. Mental flexibility on verbal tasks was measured using Category Switching: Total Switching Accuracy from the D-KEFS Verbal Fluency Test [23]. Verbal fluency measures assessed both lexical and categorical word fluency as well. Lexical fluency was assessed using NEPSY-II Word Generation: Initial Letter Total Score, the FAS task from the Controlled Oral Word Association Test, and D-KEFS Verbal Fluency: Letter Fluency Total Correct. Categorical fluency was measured using the Animal Naming subtest from the Controlled Oral Word Association Test, D-KEFS Verbal Fluency: Categorical Fluency Total Correct, and NEPSY-II Word Generation: Semantic Total Score (Table 1; [19, 23–24]). Data analyzed were age-based normative standard scores per standardized procedures associated with each measure.

2.3 Statistical Analysis

Although not all participants completed all measures, missing data were determined to be missing at random. There were no outliers and data were normally distributed. Data was assessed for possible covariates using one-way ANOVAs, revealing two covariates: SES and ethnicity. Multiple ANCOVAs were run to assess study hypotheses. Analyses were controlled for SES and ethnicity. Due to multiple analyses, the Bonferroni adjusted value of 0.01 was used for significance level.

3 RESULTS

3.1 Participant Characteristics

In this study 84.6% of children were classified as having active epilepsy (i.e., one seizure within the past year) at the time of the evaluation. Furthermore, 71.2% of children were classified as pharmacoresistant, defined for this study as having seizures that failed to respond to two or more antiepileptic medications. At the time of this evaluation, 8 children were seizure-free for 1 year, 13 had less than 1 seizure a month, 16 had between 1 and 3 seizures a month, 9 had 1 to 4 seizures a week, 5 had 5 to 10 seizures a week, and one child had daily seizures. Seizure frequency did not differ between the groups, χ^2 (2, N = 52) = 7.30, p = .19. In total, 80.8% of children had focal epilepsy, with 15.4% of these children also showing secondary generalization. The remaining 19.2% of children had generalized epilepsy. Planned analyses were run both with and without children with generalized epilepsy (Table 2), for all analyses expect Verbal Fluency: Category Switching Total Switching Accuracy, which failed to meet test assumptions. As expected, results did not differ, and thus, children with generalized epilepsy were retained in the sample for all analyses. Lateralization was not differentially distributed between the groups, χ^2 (2, N = 52) = 5.32, p = .07, nor was localization, χ^2 (4, N = 51) = 3.03, p = .55. Lateralization was trending towards a significant difference, with a greater number of children with left hemisphere focal epilepsy in the bilingual group. The majority of children in the study with focial epilepsy had seizure foci in the frontal (N = 12), temporal (N = 12), or frontal-temporal (N = 14) regions. Additionally, 2 children from each group had seizure foci in the parietal-occipital (N = 4) region. Approximately half of the subjects were receiving monotherapy (53.8%), with the remainder on polytherapy (44.2%) or no AED's (1.9%). Handedness was not distributed differently between the two groups, χ^2 (2, N = 51) = 1.23, p = .55. All children were fluent in English. Bilingual children were additionally fluent in Spanish (n = 20), Korean (n = 3), Mandarin (n = 1), Pashto (n = 1), and Tagalog (n = 1). Bilingual children all resided in bilingual or monolingual, non-English speaking homes. All academic instruction was solely provided in English.

T-tests, Chi-Square, and Fisher's Exact Test analyses were run to test for equivalency of participant characteristics. There were no significant differences between groups in health variables including age of seizure onset, seizure type, and percentage of children with pharmacoresistant epilepsy. The groups also had similar demographics, except for SES and ethnicity (Table 3), with lower SES in bilingual children as compared to monolingual children, t (50) = 4.35, p < .001. Not surprising given our variable of interest, ethnicity also differed between the two groups based on Fisher's Exact Test analyses, $p < .001$. Thus, SES and ethnicity were statistically controlled when examining group differences in executive function.

3.2 Neuropsychological Functioning

The General Ability Index (GAI) did not differ between the two groups, t (50) = 0.64, p = .53, with the mean GAI falling in the Average range for both monolingual (M = 96.38; S.D. = 12.58) and bilingual children (M = 93.88; S.D. = 15.57; t (48) = .737, p = .465). The sample population as a whole, including both bilingual and monolingual children, showed

Average range performance on the Working Memory Index (M = 87.38; S.D. = 14.54) and Low Average performance on the Processing Speed Index (M = 84.5; S.D. = 16.13). The bilingual group (M = 89.7; S.D. = 19.35) performed better than the monolingual group (M = 79.60; S.D. = 11.31) on processing speed tasks, but this difference was not significant, $t(37) = -1.89$, $p = .07$. Mental flexibility, as measured by Verbal Fluency Switching Accuracy (M = 8.23; S.D. = 2.93) and Trail Making Test Switching/ Part B (M = 6.13; S.D. = 4.00), were in the low average range. Semantic verbal fluency was in the average range (M = 8.14; S.D. = 3.01), whereas lexical verbal fluency was low average (M = 6.60; S.D. = 2.92).

3.3 Group Differences in Executive Functioning

Multiple ANCOVAs controlling for SES and ethnicity were run to compare group differences in executive functioning. These results showed that bilingual children performed significantly different on the Working Memory Index as compared to monolingual children, $F(1, 48) = 7.32$, $p < .01$, $\eta^2 = 1059.85$. Review of the adjusted means when controlling for covariates shows that the bilingual participants (M = 92.75; S.E. = 2.59) performed better on working memory tasks than monolingual participants (M = 92.76; S.E. = 2.59). There were no between group differences on other measures of executive functioning (Table 4). More specifically, there were no significant between group differences on the switching trial of the Trail Making Test, a measure of mental flexibility, $F(1, 34) = 0.14$, $p = .710$, $\eta^2 = 1.829$. Similarly, on D-KEFS Verbal Fluency: Category Switching Total Switching Accuracy, there were no significant differences between monolingual and bilingual children's performance, $F(1, 17) = 0.22$, $p = .644$, $\eta^2 = 1.686$. This task measures mental flexibility as indicated by the number of accurate categorical switches made during this task. The remaining D-KEFS Verbal Fluency tasks were also analyzed. Letter Fluency, a measure of lexical fluency, did not differ between groups, $F(1, 48) = 1.41$, $p = .239$, $\eta^2 = 9.49$), nor did Categorical Fluency, $F(1, 48) = .886$, $p = .351$, $\eta^2 = 7.350$.

4. DISCUSSION

The current study tested the hypothesis that the number of languages in which a child is fluent differentially impacts executive functioning in children with epilepsy. These results found that bilingualism is associated with stronger working memory skills in the study population, even after accounting for differences in SES and ethnicity. However, bilingualism in children with epilepsy was not associated with benefits in other areas of executive functioning, as has been found in healthy individuals, suggesting that the presence of epilepsy influences the degree to which bilingualism impacts executive functioning. These findings are unlikely to be accounted for by clinical variables, such as age of seizure onset, seizure type, and percentage of children with pharmacoresistant epilepsy, as these were similar for the two groups. Between group differences in lateralization of focal epilepsy trended towards significance, with bilingual children having higher rates of left hemisphere focal epilepsy. The bilingual group had both greater incidence of left hemisphere foci and significantly stronger verbal working memory performance, despite verbal working memory being more likely to be lateralized to the left hemisphere [25]. This may offer additional support that between group differences found in this study are in fact due to a bilingual benefit rather than epilepsy related factors. In addition, the differences in executive function between the groups are not simply a reflection of differences in cognitive function, as general cognitive abilities were not shown to differ between the groups.

Children with epilepsy are at risk for cognitive dysfunction, particularly in the area of executive functions [2, 5]. As such, these children have a two-fold risk for decreased quality of life, including reduced occupational and educational outcomes conferred by both epilepsy processes and associated declines in executive functioning [3, 4]. In a process where aspects of cognitive functioning are at risk and efforts for remediation need to be focused, the question of how much emphasis should be given to the acquisition or maintenance of a second language can arise for children who reside in an environment where a second language is not essential to day-to-day functioning. This raises previously unanswered questions. Specifically, does bi/multilingualism confer any benefits for this subset of children with epilepsy? The findings from this study support an advantage for working memory in bilingual children with epilepsy, while also suggesting that the effects of bilingualism on other executive skills may not be as diffuse as what is found in typically developing children. Working memory, which is a stronger skill in the bilingual sample in this study, is a very important skill set since working memory, independent of IQ, predicts long term educational attainment in both reading and math [26].

4.2 Working memory and Bilingualism

Two potentially conflicting processes may affect working memory in bilingual children with epilepsy; while bilingualism may strengthen working memory, epilepsy, on the other hand, may weaken this skill. This study found that the ability to speak more than one language is related to verbal working memory advantages in children with epilepsy, suggesting perhaps a protective variable in the face of epilepsy-related dysfunction. Working memory is a complex construct that involves multiple processes. Baddeley's [27] theoretical conceptualization of verbal working memory involves two core concepts, namely, the central executive component and the phonological loop. Both of these systems are at risk in individuals with epilepsy. For example, disruptions to both the central executive component and the phonological loop have been shown to negatively impact performance on working memory tasks for adults with temporal lobe epilepsy [28]. These disadvantages, imparted by epilepsy, are contrasted by potential benefits of learning a second language, which requires repeated activation of central executive skills and the phonological loop. The prevailing models for the role of enhancing executive functions have focused on how practice relates to improvements in set-shifting and inhibition, but do not adequately address the role of working memory [29–31]. Our study highlights the advantage of bilingual processes on working memory in children with epilepsy and suggests that bilingualism may impact different aspects of executive function (i.e., working memory) compared to the existing literature on typically developing bilingual children (e.g., set-shifting, inhibition).

A related body of work on cognitive remediation following CNS insults does, however, focus on the role of practice in improving working memory. Cognitive remediation is a rehabilitative process that uses systematic repeated practice of a cognitive task to improve/ restore a cognitive skill [32]. The use of repeated practice to restore function is based on Alexander Luria's theory [33] that states that stimulating neural pathways can result in functional reorganization after an insult. The use of cognitive remediation programs to address a specific weakness in working memory has been shown to be effective in CNS disorders, such as pediatric cancer, traumatic brain injury, and ADHD [34–35]. It is possible that functionally, the acquisition and use of multiple languages may rely on similar mechanisms as repetition in cognitive remediation. Bilingualism could potentially be viewed as a naturally occurring and ongoing practice of working memory. It may be that the additional areas of activation found during executive function tasks in bilingual children [35–37] reflect strengthening or reorganization of white matter connections secondary to repeated practice.

4.3 Epilepsy and Bilingualism

Although there are noteworthy differences in the neurocognitive profiles between monolingual and bilingual children, the present study, is to our knowledge the first attempt at expanding these findings to children with epilepsy, showed only one significant between group difference. Instead of achieving the same broad executive functioning benefits as is seen in typically developing children, bilingual children only demonstrated working memory advantages. At the same time, the present results do not offer support for differences in skills related to mental control (i.e., inhibition, selective attending, response time, mental switching), which have consistently been shown to be stronger in typically developing bilingual children [8, 11, 38]. We speculate that based on the differences in findings for this study from the broader bilingual research in typically developing children, epilepsy processes might mitigate the bilingual effect, potentially limiting it to only impact working memory. The present findings suggest that the impact of bilingualism on executive function skills in typically developing children may not be entirely generalizable to children with epilepsy, which could reflect differences in the organization of and relationships between cognitive skills in children with epilepsy [39]. Future studies that look more specifically at discrete executive skills and seizure foci may help further elucidate the role of bilingualism in childhood onset epilepsy.

Executive skills are diffusely located throughout the brain; however, specific aspects of executive control appear to be associated with specific brain regions. Unsurprisingly, the prefrontal cortex, an area known for its role in executive functions, is implicated in bilingualism. This has been shown for tasks such as response time, making inferences, verbal working memory, and language switching [40–42]. The caudate has been associated with motor and cognitive control and plays a role in switching between languages for bilingual individuals [41]. In addition, the left putamen, which appears to be involved in the detection of salient cues for language, shows increased grey matter density for bilinguals as compared to monolinguals [37]. The anterior cingulate cortex (ACC) also plays a role in the bilingual process by detecting and moderating conflicts in information processing. The ACC is found to have increased grey matter density correlated with better conflict monitoring for bilingual, but not monolingual individuals [36; 44]. Additionally, the presupplementary motor area (pre-SMA) plays a role in speech inhibition for language switching [36]. Lastly, the parietal lobe also appears to play a role in language switching, response time, verbal working memory, and maintenance of task representatives [40; 16].

These studies highlight the prefrontal cortex and the parietal lobe as areas related to working memory in bilingual populations. The current study showed working memory to be a strength for bilingual children with epilepsy, suggesting that one or both of these brain regions may be differently impacted in children who are bilingual and have epilepsy.

4.4 Limitations and Future Directions

This study demonstrates bilingualism as an important factor to consider when assessing executive function in children with epilepsy. However, it also has some limitations. The sample size in this study is relatively small, and a larger sample could help elucidate whether the bilingual advantage differentially impacts specific executive functions based on epilepsy syndromes. Executive function deficits are not syndrome specific, but as some areas of executive functions do appear to be impacted in varying degrees by epilepsy type and seizure foci [6], these epilepsy specific factors are possible confounds in this study. It will be important for future research to specifically investigate the impact of epilepsy type and foci on specific executive skills in the bilingual population to better understand the impact of bilingualism. Based on the results of this study, a specific investigation of frontal, temporal, and parietal seizure foci for verbal and spatial working memory in a bilingual population could help further elucidate the bilingual phenomenon. Although it is a limitation that the majority of the bilingual participants were Spanish-speaking, and this could reduce the generalizability of the study findings, this is less likely as the executive advantage has been shown to extend across diverse languages and cultures [7–8]. The retrospective nature of this study limited the specific information that was available for language acquisition in the dual language sample such that we are not able to comment on how this may impact this studies findings. The educational language, which for this study is English, often causes a language shift to English dominance, even when this was the not the native language. Although not consistently supported, there is evidence that differences in language skills for monolingual and bilingual children in the primary language of their environment are often not meaningful after 5 or 6 years [45; 46]. Family and community factors, such as SES, parental literacy, children translating for parents, use of native language in the home, and dominant language in the environment play a role in language acquisition and facility [46] and should be included in future studies. Additionally, due to the retrospective nature of the study and that data were collected from a tertiary children’s hospital, we do not have additional comparison groups including typically developing monolingual and bilingual children. However, we used standardized neuropsychological test scores and our participants were, as a group, largely functioning within the average range. Finally, inclusion of functional or structural imaging data in future research may help to further delineate areas of the brain that are important in processing and switching between language systems within a bilingual pediatric epilepsy population and could also help explore mechanisms for bilingualism that impact executive functioning in children with epilepsy.

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Highlights

- In healthy individuals bilingualism enhances executive functioning; this is a skill negatively impacted across epilepsy syndromes.
- Bilingual children with epilepsy performed significantly better on working memory tasks than monolingual children.
- Executive skills, such as switching and mental flexibility, which differ for monolingual and bilingual children in typically developing populations, did not differ in our epilepsy sample.

Table 1

Neuropsychological Measures

Instrument	Specific Scale	Cognitive Domain (Subdomain)	N
Wechsler Intelligence Scale for Children, 4th Edition	Full Scale IQ	Intellectual Functioning	n = 42
Wechsler Abbreviated Intelligence Scale			n = 2
Wechsler Adult Intelligence Scale, 4th Edition			n = 8
		Verbal Fluency	
Delis-Kaplan Executive Functioning System	Verbal Fluency: Condition 1	(Lexical Fluency)	n = 21
	Verbal Fluency: Condition 2	(Semantic Fluency)	n = 21
NEPSY-II	Word Generation	(Lexical Fluency)	n = 6
Controlled Oral Word Association	F-A-S	(Lexical Fluency)	n = 25
	Animals	(Semantic Fluency)	n = 25
Wechsler Intelligence Scale for Children, 4th Edition	Working Memory Index	Working Memory	n = 44
Wechsler Adult Intelligence Scale, 4th Edition			n = 8
		Executive Functioning	
The Trail Making Test	Trails B	(Nonverbal Sequencing and Set Shifting)	n = 20
Delis-Kaplan Executive Functioning System	Trail Making Test, Condition 4	(Nonverbal Sequencing and Set-Shifting)	n = 17
		Executive Functioning	
Delis-Kaplan Executive Functioning System	Verbal Fluency, Condition 4	(Verbal Mental Flexibility)	n = 21

Table 2

Estimated Marginal Mean Scores by Language Group for Focal Epilepsy

	Bilingual ***n*** **= 23**		**Monolingual** ***n*** **= 18**		
	M	***SE***	***M***	***SE***	**P**
Trail Making Test[1]					
Switching Condition	5.95	1.17	5.08	1.12	.625
Verbal Fluency[1]					
Lexical	7.40	0.60	5.66	0.69	.086
Semantic	8.69	0.68	7.00	0.78	.137
WMI[2]	93.21	2.78	79.00	3.20	< .01

[1] Scaled Score;

[2] Standard Score; WMI = Working Memory Index

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Table 3

Mean Scores for Demographic and Health Characteristic by Language Group

	Bilingual	Monolingual	P
Demographics			
Age (M/SD)	12.46 (3.55)	12.80 (3.12)	.714
Gender (male/female)	11/15	11/15	1.00
Ethnicity (l/a/m/e)	19/5/1/1	2/5/3/15	<.001
SES	30.07 (14.05)	45.05 (10.53)	<.001
Epilepsy Variables			
Age at Diagnosis	8.11 (4.05)	7.32 (3.45)	.447
Epilepsy Type (F/f-g/ G)	18/5/3	16/3/7	.330
Intractable Epilepsy (No/Yes)	5/21	8/18	.337
Antiepileptic Drugs (M/SD)	1.62 (0.75)	1.46 (0.71)	.451

l = Latin; a = Asian; m – Multiracial; e = European; F = Focal Epilepy; f-g= Focal with Secondary Generlazation; G = Generalzied

Table 4

Estimated Marginal Mean Scores by Language Group for Study Sample

	Bilingual *n* = 26		Monolingual *n* = 26	
	M	***SE***	***M***	***SE***
Trail Making Test[1]				
Switching Condition	6.45	1.04	5.79	0.89
Verbal Fluency[1]				
Lexical	7.13	056	6.08	0.57
Semantic	8.60	0.61	7.51	0.63
Switching Accuracy	8.71	1.13	7.72	1.22
WMI[2]	92.81	2.69	81.92	2.66

[1]Scaled Score;

[2]Standard Score; WMI = Working Memory Index